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Correlations for Fins with Impacting air Jets type Solar Air Heater

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Experimental investigation has been conducted on a collector for non-cross flow configuration. The structure incorporates fins with impinging air jets below the absorber surface. The main aim is to examine the significance of implicating both the methods on heat transfer and thermal performance of the apparatus. Testing covers a prescribed range of operating and geometrical parameters such as, fin spacing (w = 0.03 and 0.06 m), stream-wise pitch (3 cm and 6 cm), dimensions of jet (circular in shape having diameter (D_j) = 6 mm, 8 mm and 1cm), mass flow rate of air ($\dot{m}$ = 0.056–0.112 kg.s^{-1}) and (Re= 5700–11700) respectively. An appreciable augmentation in thermal performance is noticed by mutual use of fins and air jets. The experimental data collected is further processed to develop correlations for Nusselt number in conjunction with fin and jet parameters of the set up for both the techniques separately.

Keywords: Nusselt number, Reynolds number, Solar air heater (SAH), Thermal efficiency

Introduction

In recent years, the concept of inserting fins in the collector assembly and introducing impacting air jets in the design has gained ample research attention. Varieties of works are available in literature related to these two innovative and effective methods. Examples are: heat transfer from round jets[1], mathematical modelling using steady state energy balance equations[2], analysis of nozzle geometry in thermal efficiency enhancement[3,4], and application of this technique in unglazed collectors.[5] Thermal and thermo-hydraulic performance, influence of different jet arrangements, and correlations for Nusselt number and friction factor have also been derived.[6,7] Recent works includes, the analysis of thermal performance as a function of different geometrical considerations for the similar duct design under cross flow condition.[8,9] In the last decade, the methodologies highlighting insertion of fins in collector assembly have greatly attracted many researchers. The instantaneous and average values of heat transfer coefficient focussing a fin surface was determined.[10] The role of clearance between the fins was studied while assuming uniform heat transfer.[11] Variety of investigation have focused on application of fins such as: the analysis of the array of perforated design fins, study of one, two flow direction design collector having fins, analysis of longitudinal rectangular fins, research work focussing the performance of collector, fins in two pass collector, wavy fins.[12–17] The extensive review of literature confirms that researchers have deeply investigated both the options namely jet impingement technique and inserting fins in SAH duct. However, the design assembly uniting both the techniques has not been addressed adequately. It is evident from the cited works that the correlations showing role of geometrical and operating parameters based on the simultaneous application of these two methods in SAH duct has not been covered so far. In order to explain the utility of implementing both these methods it is quite imperative to devise functional relationship between the design and operating parameters of the duct. Hence, the purpose of current work is to conduct experiments on an impacting air jets with fins type SAH for a selected values of design and operating parameters mentioned above. Based upon the experimental data, a correlation of Nusselt number in conjunction with fin and jet parameters has been formulated which would be quite helpful to estimate augmentation in heat transfer by using these two described methods.

Materials and Methods

Experimental Apparatus and Procedures

Experimental apparatus comprise of blower, glass cover, simple and embedded with fins type absorber plate, a bottom plate, perforated plate having inline

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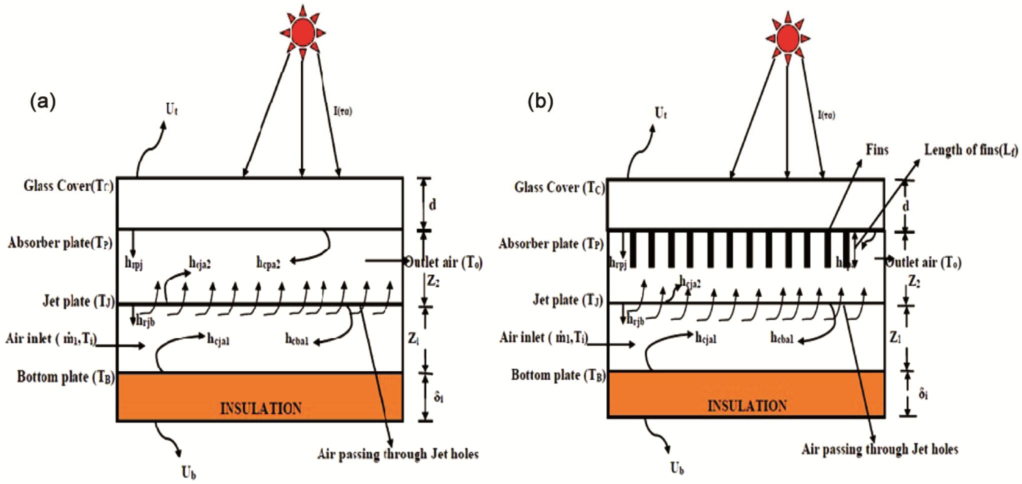

Fig. 1 — (a) Simple impacting air jets SAH (b) impacting air jets-fins

holes, voltage regulator, three digital temperature display panels (DTDU), and thermocouples attached to all plates. Exploded view is shown in Fig.1 (a) and (b). The collector is properly insulated from bottom and side by applying glass wool. Geometrical specifications of the duct are shown in Table 1 and details of instruments used with their accuracy are enlisted in Table 2. The whole structure is bent on a mechanized frame with a certain inclination. In order to measure the air velocity and temperature, the probe of DHWA is stretched inside the duct and for this provisions of drilled holes in the entry and exit side of proto-type are perfectly provided. Testing begins while assuming the steady state and non-cross flow conditions. The inlet air ($\dot{m}_1$) which is supplied through an axial blower regulated by a voltage regulator enters into the duct through lower channel. This air impinges out in the form of jets through the jet plate after which it collides to bottom absorber surface then finally exit from the upper channel. The circulated air inside the duct gains adequate amount of thermal energy when it get in touch with the underside of the absorber region. As a result it becomes hotter therefore as an outcome the air temperature raises to a fair level. The inlet velocity v_1 and v_2 in the lower and upper channels and exit velocity v_o of mixed air are measured by DHWA. The different temperatures at each section and for air also have been measured with the help of DTDU's respectively. Different test runs have been performed for simple impinging type and finned configuration separately.

Data Reduction

The computation of different quantities namely heat transfer rate and *Nu* are done with the help of collected experimental data. Also, this data is further processed to analyse the effect of impacting air jets mechanism along with the role of fins on heat transfer.

Table 1 — Geometrical specifications of the set up

Sl. No	Description of parameters	Values
1.	Collector's dimension	$2 \times 1 \times 0.14\ \{L \times W \times H\}$
2.	Plates design (Absorber and Jet)	t = 4 mm; shape: rectangle; material: GI.
3.	Glass cover	t = 4 mm
4.	Air jet's geometry	D = 6 mm, 8 mm & 10 mm, X = 3-6 cm ; Y= 6cm shape: circle pattern: inline
5.	Fins classification	L = 2 m, L_f = 12 mm, t_f = 3 mm, w= 3cm , 6cm, N_f = 20, k_{Al} = 238 W/mK pattern: continuos longitudinal
6.	Diameter (hydraulic)	D_h = 0.13m
7.	Insulation thickness	t = 2.5 cm
8.	Tilt angle	$\theta = 22.6^o$

Table 2 — Instrumentation details

Sl. No	Name of the device	Calibration
1.	Digital Hot Wire Anemometer DHWA	± 0.05 m/s for velocity ± 0.8°C for temperature
2.	Digital solar intensity recorder (pyranometer)	less than 1.0%
3.	Thermocouples	± 2.2°C

$$\dot{m}_1 = \rho \times (W \times Z) \times v_1 \qquad \dots (1)$$

$$h_{pj} = \frac{\dot{m}_1 \times C_p\ (T_o - T_i)}{A_c.(T_P - T_{a2})} \qquad \dots (2)$$

$$Nu_{pj} = \frac{h_{pj}.D_2}{k_a} \qquad \dots (3)$$

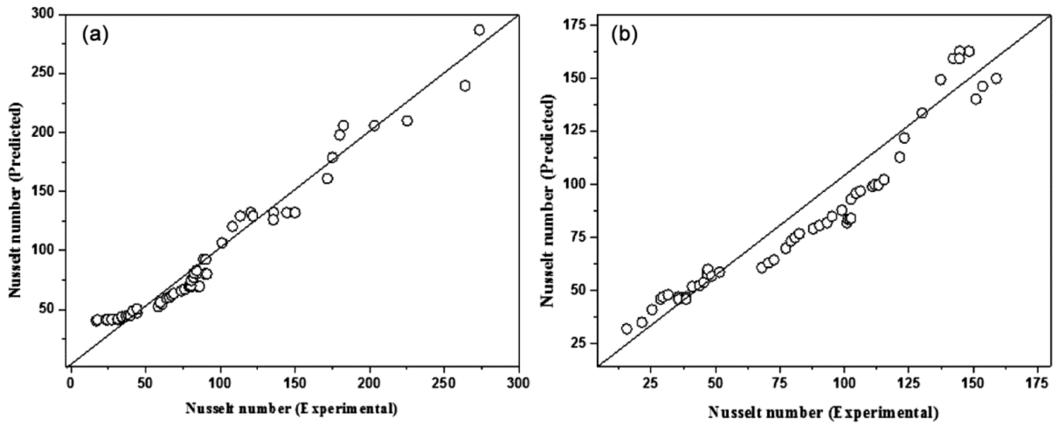

Fig. 2 — (a) Parity plot for impacting air jets- fins (b) Parity plot for impacting air jets SAH

Results and Discussion

As per the objective of current work, to predict the exact inter-dependency between *Nu* and *Re* the set of experimental data recorded for different test plates covering 76 reference points is exhausted and regression methodology is performed. The analysis generates coefficient of correlation of the order 0.98 for impacting air jets and 0.96 for impacting air jets with fins type configuration. The obtained values indicate the goodness of fit for this design of SAH. It was noted during the experimentation that *Nu* is strong function of (Re, X/D_h, Y/D_h, D_j/Dh & w/D_h). Hence, a proportional function of *Nu* may be defined as:

$$Nu=f_n \{Re, X/D_h, Dj/D_h, w/D_h, Y/D_h\} \quad \ldots (4)$$

With reference to the simple impinging jet type configuration under non-cross flow condition, the experimental data was processed and the following correlation is derived:

$$\mathrm{Nu} = 0.004 \times 10^{-5} \times (\mathrm{Re})^{2.786} \times \left(\frac{\mathrm{X}}{\mathrm{D_h}}\right)^{0.08} \times \left(\frac{\mathrm{D_j}}{\mathrm{D_h}}\right)^{-0.04} \times \left(\frac{\mathrm{Y}}{\mathrm{D_h}}\right)^{8.3} \quad \ldots (5)$$

Similarly, in case of inserting fins beneath the absorber surface the component (w/D_h) comes into effect. As discussed above separate data has been processed and the final correlation obtained is:

$$\mathrm{Nu} = 2.27 \times 10^{-7} \times (\mathrm{Re})^{2.3} \times \left(\frac{\mathrm{X}}{\mathrm{D_h}}\right)^{0.01} \times \left(\frac{\mathrm{D_j}}{\mathrm{D_h}}\right)^{-0.5} \times \left(\frac{\mathrm{w_f}}{\mathrm{D_h}}\right)^{-0.64} \quad \ldots (6)$$

From the above deduced correlations it is observed that *Re* has a direct influence on the *Nu* since the geometrical parameters holds positive exponent. With reference to the fin and jet parameters, the significance of higher positive values of exponents shows the great dominancy of these quantities on heat transfer rate as represented in Fig. 2 (a) and (b). A straight line fitted under regression analysis is explained indicating the clear fit of these data points which denotes an agreeable variation between the computed data.

Conclusions

The experimental investigation focussing impacting air jets SAH encapsulated by fins in bottom of the absorber area for non-cross flow configuration has been conducted for different set of configuration. The experimental data in the form of distinct operational and geometrical parameters was collected and further shaped into useful correlations. The correlation of *Nu* is derived with a fair value of correlation coefficient of 0.98 for impacting air jets and 0.96 for impacting air jets with fins type assembly which indicates the goodness of valid fit for this design of SAH. Also, the validity of these correlations is shown by parity plots which reveal the consistency between the computed values. In general, an absolute deviation of ± 3% for impinging jet under non-cross flow condition and ± 5% for impinging jet with fins is noticed. These values certainly infer a good agreement and validate the experiments. These correlations have been further worked out to determine the other performance terms.

Nomenclature

A_c	Collector total area (m^2)	T_o	Exit air temperature
C_p	Heat capacity (J/Kg.K)	T_j	Jet plate temperature (K)
D_h	Diameter –(Hydraullic)	t_f	Fins thickness (m)
H	Collector height (m)	v_w	Wind speed (m/sec)
I	Intensity of solar radiations (W/m^2)	W	Width of collector (m)

k_a	Thermal conductivity-air (W/m.K)	w_f	Fin spacing ,m
k_f	Thermal conductivity-Fins (W/m.K)	X	Stream wise pitch for air jets (m)
L	Length of collector (m)	Y	Span wise pitch for air jets (m)
L_{fin}	Length of Fins (m)	***Dimensionless Numbers***	
L_f	Height of Fins (m)	Re	Reynolds number
$\dot{m}$	Air- flow rate (kg/sec)	Nu	Nusselt number
N	No. of glass cover, N_f: Number of fins	***Greek Letters***	
Q_u	Useful Thermal energy gain from collector (Watt)	η_{th}	Collector thermal efficiency
T_a	Temperature of surrounding air(K)	$\tau\alpha$	Transmittance absorptance product
T_i	Entering air temperature (K)		

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